iPhone in NASA Ground Operations

a report done for

ESMD SPACE GRANT SYSTEMS PAPER COMPETITION
Kennedy Space Center, Florida

by
Team Purdue

Ashley Benedict
Keena Byrd
Lalaine Ignacio
Amit Lagu
Ralph Curtis Palmer III
April Savoy
Deepti Surabattula
Samantha Vaitkunas

April 30, 2007

EXECUTIVE SUMMARY

A comprehensive review of the literature and historical background of NASA established a need for an easy-to-implement technological improvement to displaying procedures which is cost effective and risk reducing. Previous unsuccessful attempts have led this team to explore the practicality of using a mobile handheld device. The major products, inputs, resources, constraints, planning and effort required for consideration of this type of solution were outlined. After analyzing the physical, environmental, life-cycle, functional, and socio-technical requirements, a Functional Analysis was performed to describe the top-level, second-level, and third-level functions of the system requirements. In addition, the risk/value proposition of conversion to a new technology was considered and gave a blueprint for transitioning along with the tasks necessary to implement the device into the Vehicle Assembly Building's (VAB) current infrastructure. A Work Breakdown Structure (WBS) described the elemental work items of the implementation.

Once the viability of this system was confirmed, a device was selected through use of technical design comparison methods including the Pugh Matrix and House of Quality. Comparison and evaluation of the Apple iPhone, Motorola Q, Blackberry, PC Notebook, and PDA revealed that the iPhone is the most suitable device for this task. This paper outlines the device design/ architecture, as well as some of the required infrastructure.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CEV	Crew Exploration Vehicle
DVD	Digital Versatile Disc
FCC	Federal Communications Commission
HOQ	House of Quality
IMAP	Internet Message Access Protocol
JSC	Johnson Space Center
KSC	Kennedy Space Center
LPV	Low Production Volume
NASA	National Aeronautics and Space Administration
PC	Personal Computer
PDF	Portable Document Format
PRACA	Problem Reporting and Corrective Action
QFD	Quality Function Deployment
RFID	Radio Frequency Identification
SRB	Solid Rocket Booster
TAIR	Test and Inspection Records
VAB	Vehicle Assembly Building
WBS	Work Breakdown Structure

I. INTRODUCTION

A. PROCEDURES AT NASA

National Aeronautics and Space Administration (NASA) approved procedures are written for the main assembly, maintenance, pre-launch ground check-out, and inspection tasks that are currently performed in the Vehicle Assembly Building (VAB) during Space shuttle build-up and storage operations (KSC, 2007). These procedures contain steps and instructions for very involved tasks performed by highly trained technicians. For example, a typical check-out procedure includes long hydraulic operations, powering up different parts of avionics, pressurizing and depressurizing the orbiter, and other work lasting up to 24 consecutive hours (Semmel et al., 2006).

Design engineers create and document the initial procedures for assembly, integration, and maintenance work for ground operations for each launch vehicle. The creation of these procedures results in large manuals consisting of printouts in three-ring binders. The procedure information is disseminated to the technicians through paper-based procedure manuals. When a technician is completing a procedure and encounters an error either in the procedure or the assembly, the technician completes an error reporting form and submits the form. The information is either entered into the Problem Reporting and Corrective Action (PRACA) system or submitted as a Procedure Change Request. The design engineers receive notification of the procedure error and make corrections to the procedure manual. Figure 1 illustrates the current system within the NASA design environment.

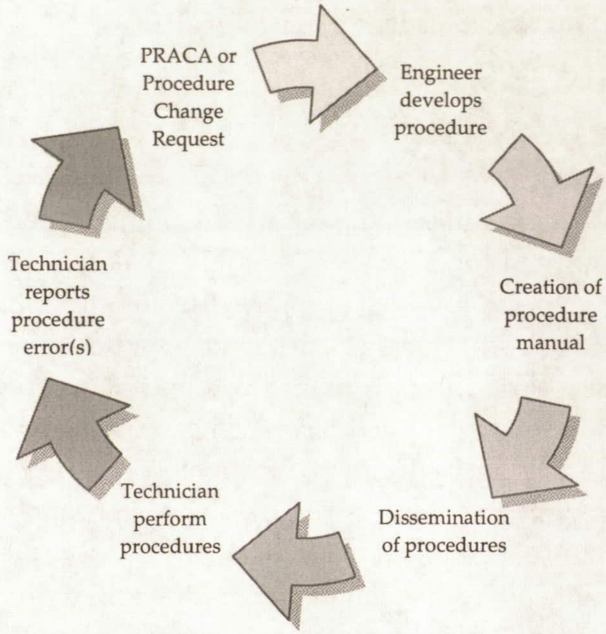


Figure 1: Current NASA design environment

NASA has been a government agency since 1958 (NASA, 2007c). NASA programs are funded by Congressional budget which require various procedures to have signoff levels. NASA uses a tremendous amount of procedures in all of its activities and each requires various signoff levels. The signoff methodology in addition to being politically motivated is also a risk management technique. The current NASA design environment suffers from several issues regarding the problem reporting process and distribution of updated procedure information. The paper-based processes increases the risk of lost forms, time delay in the transfer of forms, as well as restrictions on length of error explanations due to form size. Other issues concern the extensive process of updating the paper manuals with corrected procedure information. In order to ensure the technicians are made aware of the procedure change, the previous manuals must be located and the incorrect procedure steps must be replaced.

During the transitions from the Space Shuttle Program to the Constellation Program, the environment will be more susceptible to procedural errors. Most of the Constellation Program is based on systems originally developed for the Space Shuttle Program, although structured vehicle design is more closely related to the Apollo Program. This evolution requires the management of production transition to align the specific, better-known (but still evolving) domain of the Space Shuttle Program to the greater complexity and ill-defined parameters of the Constellation Program. While the assembly, integration, and maintenance procedures of the current Space Shuttle Program

are established and explicitly defined, the knowledge base and operational processes for the Constellation Program vehicle are being generated while the vehicle is being designed.

Operational knowledge from the Apollo Program has been lost due to workforce retirement and lack of documentation management. In the spaceflight domain, operational knowledge is defined as the documented and implicit information used to produce an appropriate outcome, such as a successful mission. These workforce and documentation issues affect the Constellation Program because the Apollo Program configurations were applicable to the required operational knowledge. The workflow procedure and operational knowledge gap between the Space Shuttle Program and the Constellation Program must be bridged.

NASA has been interested in developing and utilizing technological solutions to bridge the various disconnects. Electronic filing procedures and organization wide databases such as PRACA have been implemented in a genuine attempt to improve operations. However the attempts have not been completely successful. Some possible reasons for the failures are due to the fact that most solutions have been engineer centric and not technician centric. The unsuccessful implementation of previous solutions has not improved the quality of intra-organizational communication, measured by paperwork. Also the efforts seem almost an afterthought rather than being targeted at pro-active management of obsolescence.

Procedural changes can face difficulties due to conflicting perceptions of decision makers. Some believe that evolutionary changes can only be made to the designs or hardware/ software components and that the only way to perform a procedure is through the engineer-developed way. These incorrect beliefs should not propagate to new procedures, since this would serve to lengthen correction times and may result in imperfect or unsafe solutions. The optimum procedural system would develop and store knowledge about successful procedures, monitor success rates, and record incidental information which could help in retracing steps and rectifying procedures.

B. Problem Background

The Crew Exploration Vehicle (CEV) will be America's spacecraft for human space exploration after the Space Shuttles retire from active service. The Constellation Program proposal calls for the CEV to be operational by 2014, reflecting the President's and NASA's vision statements. The CEV is not intended to be a replacement for all types of space launches. Preliminary studies

by NASA have indicated that each spacecraft can be flown up to 10 flights and may be all or partially reusable (NASA, 2007a). Figure 2 shows the number of successful space shuttle launches through January 2007. Based on current knowledge of NASA's vision for CEV, it can be safely assumed that CEVs will also follow the low production volume (LPV) model.

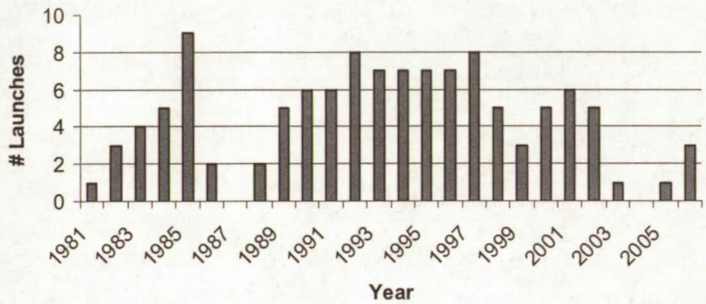


Figure 2: Number of Space Shuttle launches per year until 01/2007 (NASA, 2007a)

This project will require a narrowed focus on a particular location at NASA ground operations to make the prototype discussion more straight-forward. After reviewing ground operations at Kennedy Space Center (KSC), the VAB was chosen for the scope of this project. NASA will retire the space shuttle in 2010, and in 2008 the VAB will start the transition for the assembly and processing of the CEV which makes it ideal for this project (International Information Programs, 2005). NASA is an enormous entity, but focusing on the operations, facilities, and parts within the infrastructure of the VAB will mitigate the range of risks. For the purposes of this project, the focus will be on communication between Shuttle and Ares and the existing experience base located at the VAB.

The LPV model is suitable for the CEV for two reasons. There is a small demand for CEVs; therefore NASA can more thoroughly implement the numerous safety standards and restrictions. The low production can more easily handle potential changes in the design, production, and assembly processes. Unfortunately, the LPV environment brings along its own set of problems: the learning curve increases since technicians have only a few opportunities to learn a skill. In the case of the CEV, the problems of LPV get further compounded by the fact that CEV blueprints are comprised of design modifications and improvements to the Apollo and Space Shuttle. None of the employees from the Apollo era will be available to NASA during CEV operations, and countless current employees are reaching retirement age in this decade, thus, contributing

to the knowledge and expertise disconnect. The following statement illustrates the financial impact:

"Way back in the 1960s [NASA] spent $24 billion (in 1969 dollars)--and at one point employed 400,000 people--to send 12 astronauts to the moon. But in the 23 years since the Apollo program ended, the engineers who carried crucial know-how in their heads, without ever passing it on to colleagues, have retired or died (or both). At the same time, important blueprints were catalogued incorrectly or not at all, and the people who drew them are no longer around to draw them again. So to fulfill the Bush administration's promise to return to the moon in the next decade, NASA is essentially starting all over again. Estimated cost to taxpayers in current dollars: $100 billion." (Fisher, 2005)

NASA has experienced setbacks due to lack of funding and technology issues. In an attempt to increase efficiency, safety and reduce ground operations costs, it has pushed for improvements in integrated display interfaces (Pell & Shafto, 2004). Ground operations technicians and maintenance personnel would benefit from the use of handheld devices that would promote contextually effective interactions. NASA has considered various options and technological solutions to improve interfaces used by the crew and technicians. Members of the Real-Time Software Engineering Branch at the Goddard Space Flight Center have developed and evaluated usage of wearable, wireless, voice-activated computers using many off-the-shelf components (Pfarr et al., 2001). Similar studies have been performed to investigate usage of wearable, voice activated computers in restrictive environments such as clean rooms (Graves & Lupisella, 2004) and on task performance using wearable devices in crew maintenance activities by the Habitability Division at the Johnson Space Center (JSC).

There will be a new learning curve for the CEV program, where knowledge will be gained through both successful and unsuccessful completion of procedures. The knowledge and expertise disconnect from past to present NASA programs will be a challenge to contend with, in NASA's future operations such as lunar assembly structures and long duration space missions. The significance of knowledge transfer heightens with the growing need to reduce problem resolution errors and time. The purpose of this project is to develop and examine a systems based solution to improving the communication, safety, and efficiency for ground operations processes and procedures at NASA. This systems engineering approach will facilitate space exploration technology and the factors directly affecting mission execution and success; thus, fulfilling the President's and NASA's agendas. Specifically, this project will explore whether operations can be improved when assisted with a portable electronic device as well as the obstacles to, requirements of, and infrastructure for transitioning to such a device. The remainder of this paper will clearly outline

the systems processes and methodology for using a portable, web-enabled device to complete operational procedures at NASA.

II. Systems Engineering Process

A. Systems Engineering Process Planning

A new system utilizing both commercially available products and existing NASA technology has been envisioned to help NASA reduce ground processing person-hours, increase efficiency, improve safety, and reduce ground operations costs at KSC. Technology evolutions in mobile devices will be incorporated in the work-flow to help achieve the goal with low implementation cost and high results.

Major products and results from process

There are two levels of system – technological and infrastructural. The technological level would encompass the databases and the mobile device. A procedure database was created for the Delta and Atlas launches, which have benefited from the electronic procedure/work control systems. The technology already exists in NASA, it needs to be expanded and implemented in other areas. Electronic procedures would be highly interactive and dynamic. Parts of the procedures can be updated whenever new procedural steps are included or deleted. The PRACA database exists in NASA but its implementation was not fully integrated with other aspects of production planning and control. Technology in the field of mobile devices is advancing at a very fast pace and many tasks which required the technicians to leave their workplace can be now performed without doing so. For the implementation of the proposed system, the technicians should be able to access the databases using the internet or intranet. This in turn means that the databases should be on a NASA server and all the technicians should have the right to access internet. This requirement raises infrastructural issues. This is the other level of the system. Infrastructural changes need to be made to accommodate the requirements of the proposed system.

Process Inputs

Infrastructural changes are also important to the introduction of the proposed system. The mobile device would require communication capabilities

at the technicians' workplace. A communication tower for good reception is required. The mobile device needs to have both short and long range wireless capabilities to access the procedures and report errors using the internet/intranet. These technologies might interfere with the working of certain components of the assembly. It might seem expensive to make the infrastructural changes for VAB only. But in the long run if the cost of implementing the infrastructural changes in all the NASA facilities is considered, the reduction in production cost would be much higher than the implementation cost.

The proposed system would work with the integration of a procedure database (where the procedures for the assembly tasks would be stored) and the PRACA database (used for error reporting and prevention) which would be accessed using a mobile device.

CONSTRAINTS

Implementations of the infrastructural changes pose numerous constraints to the implementation of the proposed system. Changes in the infrastructure without compromising document security are a major issue. NASA procedures are sensitive and security is a high priority. The databases should be on a NASA server and all the technicians should have the right to access internet. Highly secure password protected networks should be used to prevent unauthorized access to the wireless network. The mobile devices used can also be password protected to reduce the risk of proprietary information being leaked, and all emails and internet usage crossing the wireless network should be completely encrypted.

RESOURCE ALLOCATION

Resources for the proposed system are the mobile devices which should be available to quality, safety, and engineering personnel, specifically technicians and inspectors, working at VAB and the two databases (procedure database and PRACA) which should be accessible to all.

WORK AUTHORIZATION

The present system at NASA is an authoritative system. All the technicians have a supervisor to whom they report. Whenever an error is detected, it is reported to their supervisor who passes the information on to the engineering group. With the proposed system, the time to report an error would be considerably reduced. The problem reporting to the supervisor can be done using the mobile device without leaving the worksite. Also the technicians would have the freedom to report errors directly in to the PRACA system.

Allowing the technicians more involvement in editing the procedures will help create better, more technician-centric, procedures.

Verification Planning

The error reporting and error correction will be done electronically to verify the status of the error. Also, as the procedures would be accessed online from the procedure database, it would be easier to detect where the error occurred, whether the procedure is wrong or the technician made a mistake. The proposed system would considerably reduce the error detecting and recovery time.

Subcontract/supplier technical effort

The PRACA database is already being used by NASA in a limited capacity, but the proposed system will rely on it extensively. The mobile device is a commercially available off-the-shelf product. In-house production is a good option for security reasons. If it is subcontracted the risk of security will be high.

B. Functional Analysis and Allocation

A functional description of the system is necessary during the preliminary identification of resources required for a system to complete its purpose (Blanchard & Fabrycky, 2006). The functional flow block diagram in Figure 3 depicts the top-level, second-level, and third-level functions of the system requirements.

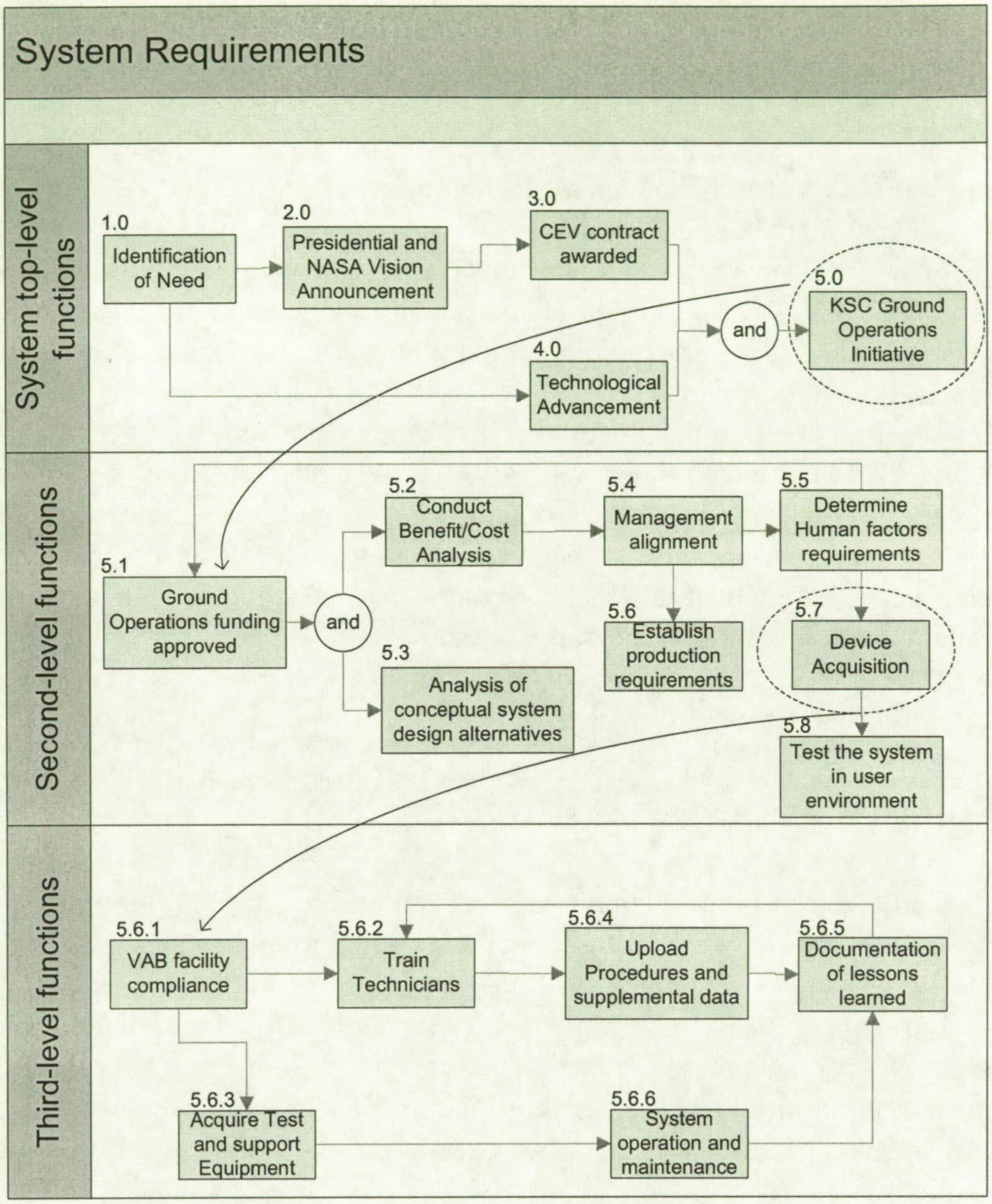


Figure 3: Functional Flow Block Diagram (after Fabrycky & Mize, 2006)

At the top-level are the high-level administrative requirements. Back in January of 2004, President Bush publicly announced a new vision for space exploration and returning to the moon. NASA then announced new goals for the next two decades requiring the CEV to be ready in 2014. Shortly thereafter a request for proposals was released and Northrop Grumman, Boeing, and Lockheed Martin submitted bids to do the build the vehicle. At the same time, there was ongoing improvement to mobile computing technologies with small

screen sizes. Once the contract was awarded to Lockheed Martin, the NASA centers began their preparations.

Currently at the second-level phase, management is developing requirements for personnel, resources, and equipment. Ground operations funding for system improvement techniques are in the process of being approved and detailed requirements from the VAB business units are being developed. Next, several design alternatives and types of handheld devices will be evaluated. Finally, the human factors and production requirements will be established and a full release version of the iPhone will be obtained for testing in a high fidelity environment.

The functions at the third-level are directly involved with production. Once the VAB is found to be compliant to the device architecture requirements, the technicians will receive training; materials and equipment that support the device are acquired; and new procedures are uploaded to the server. Once the selected device is placed into regular use, system maintenance and documentation of lessons learned are ongoing continual processes which provide feedback to the system. Appendix I documents the resources that must be allocated for each function described in the system requirements.

C. Requirements Analysis/ Validation

Constellation Program vehicles, Ares and Orion, require optimum ground operations to improve productivity, safety, and cost-effectiveness, which will enable these vehicles to launch on time. As shown in Figure 4, these efficient ground operations need to be implemented by early 2010. Technology must be selected for both the device and infrastructure. First, a multi-functional device for technicians is required to facilitate information transfer within the organization: engineers, managers, inspectors, other technicians, etc. This device will outline the requirements for the infrastructure.

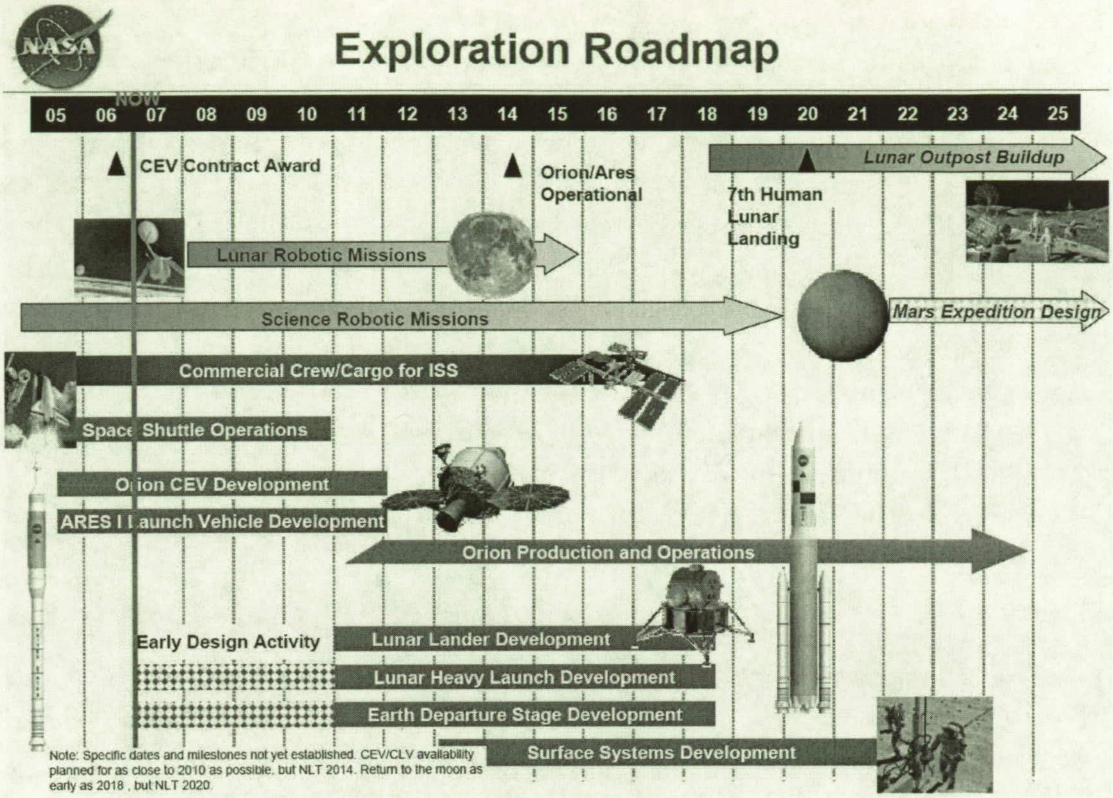


Figure 4: Constellation Program Exploration Roadmap (NASA, 2007b)

The requirements for this multi-functional device are based upon known operational and task requirements.

PHYSICAL REQUIREMENTS/ HUMAN FACTORS

- *Handheld:* Technicians need to be able to take this device wherever procedures need to be performed; this implies both lightweight and portable. The device cannot be too large or heavy which could prevent technicians from accessing critical assembly areas.
- *Wearable/Stand Alone:* Technicians need to be able to wear the device in situations where there is no appropriate area to place the device or when they need to access the device immediately.
- *Easy to Learn:* The device should not require extensive training. The device is a means to improve progress, not to interfere. The device needs to fit the technicians' knowledge and be user friendly.
- *Multi-functional:* The device needs to offer many features since the technician cannot carry and utilize multiple devices at one time.

Environment

- *Limited interference:* It is integral that the device not interfere with any portion of the assembly. Therefore, the device needs to be non-magnetic, non-corrosive or reactive with chemicals, and in compliance with part 15 of the FCC rules.
- *Backlit:* Technicians may be required to work in low lit areas where they must be able to follow procedures and communicate with others. The device screen needs to be visible in situations where there is little or no lighting.
- *Climate:* The device must function within the VAB throughout the year with temperatures ranging from 19°F to 101°F (Weather Channel, 2007) and an annual humidity of 90% (CityRating, 2002).
- *Range:* The device needs to work throughout the 129,428,000 cubic feet (KSC, 2007) of the KSC VAB.

Life-Cycle Issues

- *Durable:* The device needs to handle daily wear: resistant to scratches and dents and withstand being dropped from a short distance (< 2 ft).
- *Cost:* The device needs to have a low Risk/Value Proposition. This means that there needs to be a low risk and a high value. The device should contribute a large value to the project and have low associated risks. High value implies multi-functionality in that the device should have many features of several devices both reducing the cost of several devices and enhancing the capability of the one device.
- *Low maintenance/serviceability:* The device needs to function with no interruptions to daily work. Any routine maintenance should not interfere with daily work.
- *Reliability:* The mean time to failure should be 12 hours usage for 300 days (3600 hours).

Functional Performance

- *Access/contain electronic media:* The device needs to be able to display electronic media such as PDFs, pictures, videos, audio clips, etc. which will allow the technicians to perform procedures.
- *Access internet/ email:* The device needs to allow technicians to communicate electronically with other members associated with the program. This will help increase communication and reduce time lag between individuals.

- *Phone:* The device needs to allow technicians to call other members associated with the program. This will reduce the information lag between individuals since technicians would not have to wait for a response by email or leave their work place to speak with someone.
- *Camera:* Technicians need the ability to communicate visually with members associated with the program. The ability to take pictures can enhance the information transfer and allow for problem areas to be handled quickly and appropriately.
- *Memory:* The device needs to be able to store procedures, pictures, or notes. The device should meet current standards.
- *Battery life:* The device cannot stop working during a procedure and should last at least 4 hours. Battery life is determined as half of an 8 hour work day. It must be rechargeable within 4 hours.
- *Adaptable:* The device should allow for improvements and changes to be made during the life cycle. This is integral to assure optimum performance.
- *Wireless:* The device needs to be able to access information both short and long range. It should meet the current wireless standards.

Social, Political, and Legal Requirements

- *Safe*: The device can not place any of the technicians in physical harm.

Requirements for the infrastructure are approximated and given below.

Environment

- *Range:* The system needs to enable the device to work throughout the 129,428,000 cubic feet (KSC, 2007) of the KSC VAB.
- *Communication:* There needs to be a communication tower to support the device.

Functional Performance

- *Procedural Databases:* The system needs to allow NASA personnel to access PRACA and procedures database.
- *Access internet/intranet:* The system needs to allow NASA personnel to access information through the internet and/or intranet.

Social, Political, and Legal Requirements

- *Legal*: The electronic signature needs to be considered a legal signoff.
- *Security*: Allow only authorized users to access the system.

D. Systems Analysis and Control

Systems analysis is the comparison of different alternatives, across multiple criteria, to help identify and make better decisions. The typical use of systems analysis is to guide decisions on issues such as national or corporate plans and programs, resource use and protection policies, research and development in technology, regional and urban development, educational systems, and other social services. Quality Function Deployment (QFD) is a flexible and comprehensive group decision making technique and is used for comparing various alternatives. The Pugh Matrix is a scoring matrix used for concept selection, in which options are assigned scores relative to criteria. The device selected from the Pugh Matrix and QFD analysis is then analyzed in detail. Interface management for the device is carried out to ensure interface definition and compliance of the system with other system elements with which it interoperates. A Work Breakdown Structure (WBS) captures all the elemental work items of a full-scale implementation in an organized way. A Gantt chart is a matrix cross listing work items and estimated task duration. In risk-benefit analysis, a value is assigned to a sample set of existing risks so as to make possible a comparison of the discounted sum of these costs. The risks considered are usually events whose probability of occurrence is low, but whose adverse consequences would be important (e.g., events such as an explosion of a component on CEV or failure to launch on time). The system can be broadly classified as shown in Table 1.

Table 1: Systems Classification

Category	Value
Risk Class	Technology demo (more technology oriented than theory-based)
Development schedule	Fast (< 2.5 years)
Lead organization (KSC) level of expertise	Medium. There is a level of expertise available with respect to implementing electronic procedures in the form of PRACA
Software Heritage	Medium. PRACA has been implemented in desktops and can be reused to some extent
Software Architecture	Java, OS X
Design Complexity	Medium. New routing and access structures would need to be developed
Hardware Heritage and	No heritage, since iPhone or any similar

Redundancy	component has not been in use. There would some redundancy as it is aimed at replacing paper and desktop PRACA versions
Training required	Technicians will need to be trained on using the iPhone capabilities and using the correct procedures
Instrument Support	Low with routine maintenance. Possibly some interaction with other instruments in the future.

Based on the above classification, advanced products viz. PC Notebook, PDA, Blackberry, Motorola Q and iPhone were selected as candidate devices. These devices were then subjected to different analysis based on the requirements stated in the previous section, to determine the best fit for the VAB environment.

QUALITY FUNCTION DEPLOYMENT

QFD is a flexible and comprehensive group decision making technique used in product or service development, brand marketing and product management. QFD can strongly help an organization focus on the critical characteristics of products or services (new or existing) from the viewpoints of the customer market segments, company, or technology-development needs. QFD uses a series of matrices to represent the product comparisons and is sometimes referred to as the House of Quality (HOQ) due to its distinctive house shaped appearance. The QFD methodology is based on a systems engineering approach consisting of the following general steps:

1. Derive top-level product requirements or technical characteristics from customer needs. Once needs are summarized, consider whether to get further customer feedback on priorities. Undertake meetings, surveys, focus groups, etc. to get customer priorities. State customer priorities using a 1 to 5 rating, with 1 indicating not important to 5 indicating most important.
2. Develop product concepts to satisfy these requirements. Correlate the customer needs with the concept features. These help define the degree to which as product requirement or technical characteristic satisfies the customer need. The weights

used are 1-3-9, with 1 indicating low correlation to 9 indicating high correlation.

3. Determine potential positive and negative interactions between product requirements or technical characteristics using symbols for strong or moderate, positive or negative relationships.
4. Calculate importance ratings. Multiply the customer priority rating by the improvement factor and the weighting factor associated with the relationship in each box of the matrix and then add the resulting products in each column.
5. Evaluate product concepts using the 1 to 5 scale, with 1 indicating worst and 5 as best, to select most optimum. The scale reflects how well an attribute was obtained and not in regards to its superiority to the other technologies.

The HOQ, in Appendix J, determined the optimum device to be the Apple iPhone. Apple iPhone scored higher than other candidate devices with a total score of 297, indicating the best match between the product concepts and the developed requirements. The next best candidates were the Blackberry, PDA and MotorolaQ respectively. The paper version and the PC Notebook were found to be the least favorable candidates, indicating that an upgrade in technology to the tools might be helpful. The iPhone performed better on meeting the functional performance and physical requirements, as it combines much needed technologies in a user friendly environment and cost effective manner.

PUGH MATRIX

A Pugh Matrix compares concepts based upon the design/system requirements to determine the optimum device (Murugappan & Keeni, 2002). For the first iteration, one of the concepts is chosen as the datum. To this concept, all others are compared. Concepts which are superior are noted with a '+', inferior with a '–', and similar with an 's'. After the concepts have been compared for all requirements, each concept's score types (+, - , s) are summed. The '-' sum is subtracted from the '+' scores to obtain the final value ('s' values do not contribute to the final score). Negative final scores imply that concepts are inferior to the datum and positive scores are superior. Iterations are performed with new datums until there is one remaining concept with a positive sum, implying that it is the best concept overall.

The Pugh Matrix, Appendix H, determined Apple iPhone as the best device by comparing the physical characteristics, communication abilities,

display interface, and additional features of the Motorola Q, Blackberry, PC Notebook, and PDA. The Apple iPhone consistently scored higher. iPhone was the smallest device at 4.5" x 2.4" x 0.46". Its memory exceeded the others by far at 8000 MB and was one of the top two devices with the longest battery life. Among the devices that were both backlit and light sensing, it had the largest display size.

WORK BREAKDOWN STRUCTURE AND GANTT CHART

WBS, Appendix C, is a result-oriented family tree that captures all the work of a project in an organized way. It is often portrayed graphically as a hierarchical tree or as a tabular list of "element" categories and tasks or the indented task list that also appear in the Gantt chart schedule (Appendix D). A Gantt chart is a matrix which lists on the vertical axis all the tasks to be performed. The horizontal axis is headed by columns indicating estimated task duration. For this document, each period is expressed in 3 months. It should be noted that the final implementation for this project should coincide with the Orion production and operations, as shown. This would enable better & longer workforce training leading to better Orion operations. Any slips in timelines and implementations would lead directly into the initial Orion productions and possibly leading to enhanced error rate. The ideal project approval time window would expire in the third quarter of 2007.

INTERFACE MANAGEMENT

An interface is the formal and informal boundary/ relationship between people, organizations, and functions. Interface management is defined as the management of communication and coordination between the device and other components, both existing and future. A preliminary level analysis of first-level systems that the iPhone directly interacts with is shown in Table 2. The components of this analysis include:

- *Interface Function:* specifies "what" the interfacing system must perform (i.e., task, activity, or action).
- *Design Interface Constraint:* specifies codes and standards applicable to the interface, specific design, operating or maintenance configuration and essential features, etc.
- *Physical and Performance Requirements*: specifies physically related characteristics for components at the interface boundary as well as how a function must be performed.

Table 2: Interface Analysis

SYSTEM	INTERFACE FUNCTION	DESIGN CONSTRAINT	PHYSICAL AND PERFORMANCE REQUIREMENTS
Technician Work Scheduler	Inform technician of task / step at hand; Update central database upon completion	<u>I/P:</u> Objectives from task; Procedure(s) and forms for task; Supporting information and timelines <u>O/P:</u> Time taken; Deviations as noted by the technician; Usage statistics & record for retracing time and steps <u>Other:</u> Scrollable; Trigger time and format can be selected by the technician	Wi-Fi enabled; Support document formats (such as PDF); Touch screen enabled
Voice Correspondence	Allow for voice correspondence to and from the technician at any given time	Should not interfere with technician performing an ongoing procedure step or filling out a form	Wireless enabled
Case / Issue Management	Allow for filing of problem reports; Allow for filing of procedural compliance reports; Problem disposition status notification to technician	Should allow for reporting and searching reports; Should allow for issuing updates; Should allow for electronic signoffs	Wi-Fi enabled; Support document formats (such as PDF); Touch screen enabled
Procedure Requirements Management	Allow for filing of procedure problem reports; Problem disposition status notification to	Report compliance of correct procedure; Report incompliance of correct procedure; Report compliance of incorrect procedure;	Wi-Fi enabled; Support document formats (such as PDF); Touch screen enabled

	technician; Support procedure rollbacks	Report incompliance of incorrect procedure; Use Voice reports to supplement reports	
Procurement, Purchasing and Requisition	Enable real time monitoring of product availablity and location	Report component's usage and failure statistics; Report additional information on usage and failures	Wi-Fi enabled; Radio Frequency Identification (RFID) detection enabled
Content Authoring and Publishing	Support procedure rollbacks; Support content change requests	Notify wrong document retirements; Help update wrong content authoring	Wi-Fi enabled; Touch screen enabled Support document formats (such as PDF)

RISK BENEFIT ANALYSIS

The Risk Benefit Analysis is an evaluation of the current products/processes against the recommendations suggested in this report such as the iPhone and other electronic databases. These recommendations should result in a reduction of risks, in turn stemming financial losses and schedule creeps. The risks considered are categorized into technical risks, cost risks, schedule risks and program risks; and comprise primarily of risks relative to the currently preferred paper-based process. Technical risks comprise of failures of the product capabilities/process to achieve their desired intent. Technical risk exists if, in the system design and development process, it appears that the system will not meet a specific performance objective. The level of detail for these risks can vary. Detailed task level malfunctions are beyond the scope of this document. The risks in which the possibility of allocated budget will be exceeded are categorized as cost risks. Schedule risk can be incurred if the program schedule is not met or there is a task creep. Failure risks which can be attributed to occurrence of externally influenced events which impact this project technically, cost wise and schedule wise are categorized under programmatic risks. The scope and impact of all risks are listed vertically and correlated to each risk on a scale of High-Medium-Low. An estimate of the relative reduction in probability of each risk occurring, using the new product/process recommendation, on a scale of Small-Medium-High is done. The Risk Benefit Analysis, Appendix G, determined that recommendations showed a reduction in probability of occurrence these risks. The benefits due to the risk reduction can be easily estimated to exceed the cost of implementation of the new products.

E. SYNTHESIS

NASA ground operations presently use paper procedures to perform the tasks involved in building the Space Shuttles. A cost effective method is required to help technicians complete procedures and communicate with co-workers more efficiently and effectively. With the development of increasingly small, light, and mobile electronic devices, there is a need to understand how this technology can help technicians in their work. A Pugh Matrix was created to compare mobile technologies based upon the design/system requirements and determine the optimum device. From the results of the Pugh Matrix (Appendix H) and House of Quality (Appendix J) it was concluded that the Apple iPhone was the best mobile device that met our defined requirements.

The basic requirements for a hand held device for NASA technicians and the features of iPhone that comply with these requirements is shown in the Table 3.

Table 3: Mapping of user requirements and features of iPhone (Frakes & Seff, 2007)

REQUIREMENTS	FEATURES OF iPHONE
Physical Requirements/ Human Factors	
Handheld	Apple iPhone is 4.5in X 2.4in X 0.46in in size and weighs 4.8 ounces.
Wearable	A wearable cover can be designed for the iPhone which can be worn on the forearm or velcroed to the suit.
Steep learning curve	The iPhone is easy to use as its works similar to an iPod (touch-sensitive) and it has all the functions of a phone. The operating system is OS X, web browser is Safari and for convenience in typing it has a touch-sensitive QWERTY keyboard.
Environment	
Limited interference	iPhone does not interfere with magnetic fields.
Backlit	iPhone screen adjusts to the light of the area where it is being used.
Environment	iPhone can be used at normal temperature and humidity.
Life-Cycle Issues	
Durable	The touch screen is more resistant to scratches than the screens of iPod.
Cost	The iPhone costs $599 a unit.

Low maintenance/serviceability	Does not require any regular maintenance. Any non-functioning parts (if there is any damage or repair) need to be sent to Apple for replacement or repair.
Guaranteed function for certain time	Apple's guarantee and warranty policy
Reliability (mean time to failure)	Since the first release of iPhone is in June 2007, the reliability of the iPhone cannot be determined.
Functional Performance	
Access/contain electronic media (PDF, pictures, videos, audio)	iPhone comes with two storage capacities - 4GB or 8 GB. PDF documents can be opened in iPhone. Music and videos can be watched from iTunes. If needed there is a DVD ripper to convert audio/video formats to the Apple mp4 format. Pictures can be synced from a PC or Mac to send and view on iPhone.
Access internet, email	802.11b and 802.11g Wi-Fi.
Phone capabilities	Touch screen dialing, Conference calls, Interactive voice mail
Battery life	The Battery life is 5 hours talk-time/video/browsing, 16 hours audio.
Ability to take pictures	2.0 Megapixel camera
Adaptable (allow for improvements, changes)	Apple allows different software to be built and run on the iPhone.
Social, Political, and Legal Requirements	
Safe (no danger of physical harm)	All software built for the iPhone need to be approved by iPhone.

Since the procedures used to create the CEVs will be different than those used to build previous vehicles, a good error prevention and reporting system is required. This system is needed to track down the errors, to prevent propagation of errors, and to rectify the errors as soon as possible. Apple iPhone can be used effectively in this process. The mobile device would be helpful accessing the procedure database to download online procedures, as well as report and correct errors using the online forms. The flowchart in Figure 5 shows the steps involved in following the procedure using the PRACA database and reporting errors if the procedure is wrong. If the technician feels that the procedure is wrong, he can either call his supervisor (assuming that a supervisor is responsible for a group of technicians) or check if he is using the correct procedure by searching the PRACA database to verify if he has the correct procedure. If he finds an error in

the procedure, he files an Interim Problem Report, Problem Report or Discrepancy Report online from his workplace using the Apple iPhone.

In the present system, the technician uses paper procedure to do the assembly. If he finds an error in the procedure, he can either fill an online form on a computer at the Test and Inspection Records (TAIR) station or he can fill a paper form. Technicians do not carry these forms with them so they jot down the required information and fill the forms at the TAIR station either online or using paper forms. If they forget to write down some information, they need to go back to their workplace, write down the information and come back to the TAIR station to finish the form. Using the iPhone this process of moving back and forth for missed information will be eliminated and the error will be reported quickly (Linde & Wales, 2001).

CASE 1: The procedure is correct and the technician performs the task correctly. The task is done without any errors.

CASE 2: The procedure is correct but the technician performs the task incorrectly. There is an error in performing the task.

CASE 3: The procedure is wrong but the technician follows the procedure correctly. Though the procedure has been followed correctly there is still an error because the procedure is wrong.

CASE 4: The procedure is wrong and the technician makes a mistake in following the procedure. The task has been performed incorrectly.

There is a fifth case which leads to error when the procedure is right and the technician completes the task without errors but there is a flaw in the design. Under such circumstances, the assembly will not work and the mission is not accomplished. This case is out of the scope of this paper and will not be dealt with, however the procedural system may be able to help diagnosis design problems.

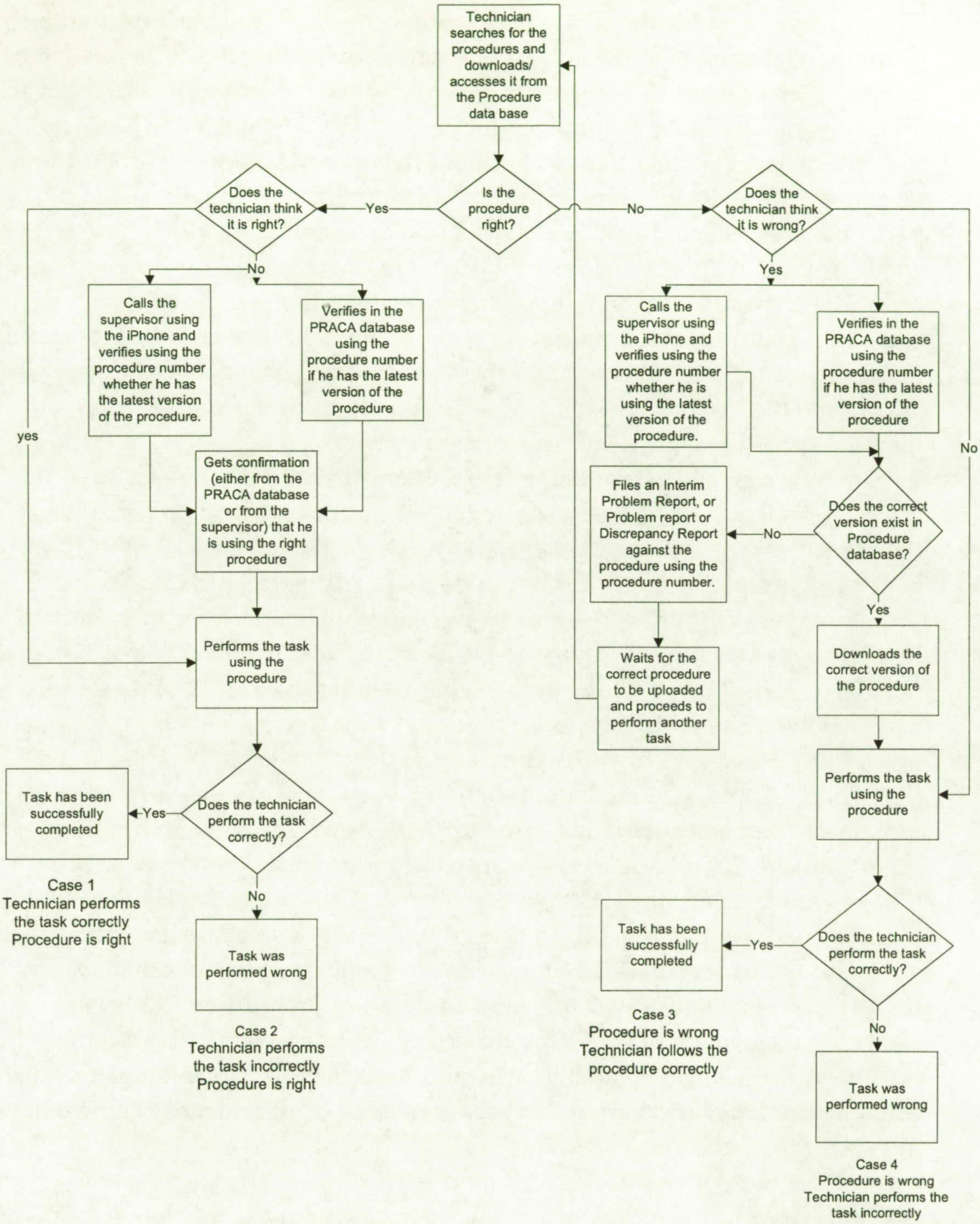


Figure 5: Task Analysis Flow chart showing errors committed while using the procedure

There should be a method/process to find and rectify the errors committed (as shown above in Figure 5) while completing the task. One method to find an error that has occurred is to have a down stream technician alert that an error occurred if he determines the unit was misassembled. The technician files an Interim Problem Report, Problem Report or Discrepancy Report online using the Apple iPhone, stating that an error occurred during the assembly of a particular component. PRACA assigns a ticket number to the report and send an email to the supervisor whose technician was responsible for performing the task. The supervisor would then check whether the technician followed the correct procedure or if the procedure was updated after the task was completed. If the procedure was updated after the task had been completed, the supervisor assigns another technician to rectify the assembly using the correct procedure. If the procedure was correct but the technician performed the assembly incorrectly, the supervisor would assign the task to the same technician again and ask him to correct his mistake. The supervisor updates the error reporting system and closes the ticket.

If the procedure has not been updated and the technician performed the procedure correctly using the wrong procedure, the supervisor files an Interim Problem Report, Problem Report or Discrepancy Report online using the Apple iPhone. He would wait till the problem has been resolved. After the problem has been resolved, he assigns a technician to rectify the error using the updated procedure. He closes the ticket after the job has been completed by the technician. Apple iPhone would help in speeding up this process as the technician need not report the error to the his supervisor who would in turn report the error to the supervisor whose technician made the mistake. Using the iPhone would reduce the time to rectify errors. Also, if a technician feels that the procedure is wrong he can raise a ticket in the PRACA database and can state the error and the correction (if he knows it). The engineers (who also have access to the PRACA database) can verify and update the procedure. This process will save critical assembly time. If a launch is delayed due to setback in assembly and manufacturing, NASA's reputation would be tarnished and millions of dollars could be lost. The flowchart of this proposed error management system is shown in Figure 6.

Sometimes the components used in the assembly fail to work or the assembly does not work because of a design flaw and the mission is called off. There is a great financial loss in such situations. Quality or safety inspectors constantly inspect the assembled parts to verify if the assembly was performed correctly and if the all the components of the assembly are working. If they detect any flaws in the assembly or in the components, it is reported in the PRACA by filing an Interim Problem Report, Problem Report or Discrepancy

Report. Apple iPhone can help speed up this reporting process and the error can be rectified as soon as possible. In case there is a design flaw, this situation is beyond the scope of this paper.

The Apple iPhone is a commercial off-the-shelf product, slated to be released in June 2007. The introduction of iPhone into the workflow of technicians would not require any new developmental items, except to make the procedures available in electronic format. All the other activities required of the technicians can be performed using internet facilities such as email, web browsing, etc. The new technology can be implemented with non-developmental items and hence it would be cost effective for NASA. Any software written for the iPhone has to be approved by Apple but, if the procedures are in a database that can be accessed using the internet, NASA would not have to get approval from Apple.

Assumptions:
1. A supervisor is responsible for a group of 10 technicians
2. The supervisor has a record of the procedures used by the technicians working under him.
3. If a technician/quality or safety inspector detects that the task was performed incorrectly by a technician, he can report the error using the PRACA database.
4. A database for all the procedures exists.

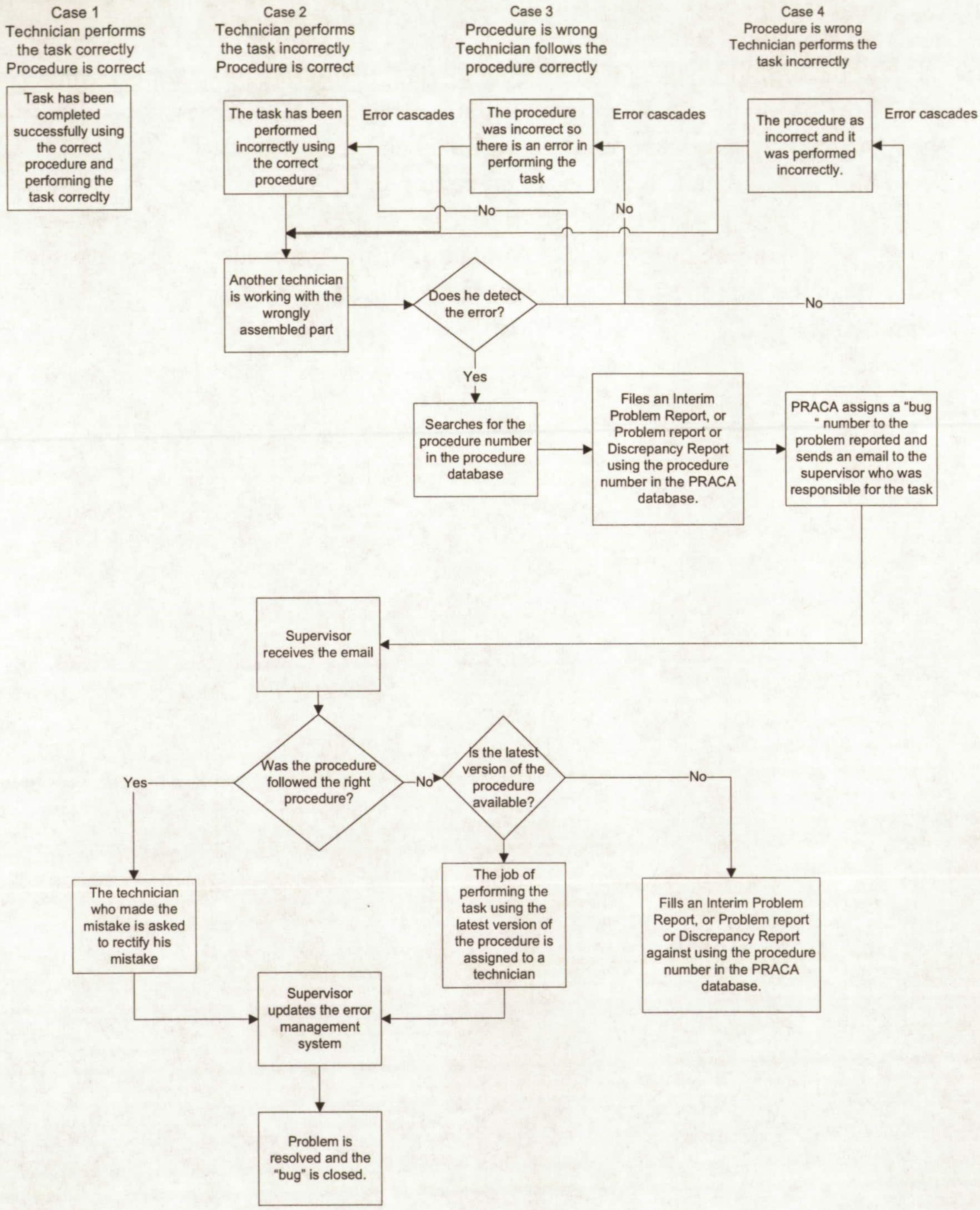


Figure 6: Flow chart of the error management system

III. Transitioning Critical Technologies

Currently the KSC VAB relies on a paper-based procedure system. The transition to a completely electronic-based procedure system is perfectly timed with the development of vehicles Orion and Ares. Procedures required to build these new vehicles are largely different from procedures in the past due to the new designs and technology. Existing designs, such as the Solid Rocket Boosters (SRB), will be used for the new vehicles; however these procedures will need to be updated and reproduced.

The critical component of the transition lies in the framework which will facilitate the transfer of the electronic-based procedures. NASA's intranet web-based system will be utilized. This will allow only NASA employees to access web pages of documents, specifically procedures. Technicians need to be able to access the network from any location within the VAB; there should be adequate wireless coverage to accommodate this need.

It is recommended that the number of iPhone units purchased equate to 60-65% of the head count of technicians. This percentage accounts for the two work shifts of technicians (50%) and unavailable units (10-15%) due to low battery or damage. This will allow for technicians to recharge units while having access to fully charged ones. In the situation where a unit fails, there will be extra units to take its place. This is vital because instrument downtown could impede vehicle assembly.

The iPhone was selected as the device of use since it performed best overall in the House of Quality (Appendix J) and Pugh Matrix (Appendix H). In addition, the iPhone was superior to the other technologies due to its multi-functionality and corresponding high value added features.

Table 4 illustrates some potential risks involved with the transition to the new technology due to the infrastructure requirements.

Table 4: Potential Risks Due to Transition of Technologies

Risks	Risk Mitigation
Wireless network goes down	Create network terminals with docking stations on wired system.
Intranet server goes down	Computer with dock-connector port containing most recent version of all documents.
Data corruption/loss	Redundant copies of documents placed on designated network computer.

IV. INTEGRATION OF SYSTEMS ENGINEERING EFFORT

The ground operations at KSC's VAB are a complex system due to the size and magnitude of its many functions and operations. Development of a complex system requires organization and integration of design disciplines. Teams performing design disciplines within the complex system may be working at different levels of detail each exploiting its own style, expertise, and models. The technical disciplines in support of the integration of the systems engineering effort are: requirements analysis and generation, procedure development, system architecture development, system performance analyses, modeling, integrated test and verification, troubleshooting and anomaly resolution (MEI Technologies, 2007). It is imperative that NASA invest in infrastructure architecture to rationalize, standardize, and structure their infrastructure landscapes.

- Requirements analysis and generation: Each team must generate well-defined and well-understood requirements for using the iPhone in their area. Analyzing and identifying functional and conceptual requirements can be a challenge; however, introducing new requirements into existing systems later on can result in costly rework or incorrect procedures. Preparing a transparent and structured taxonomy will yield greater insight into the elements of the complex infrastructure.

- Procedure development: Each team should announce its intention to develop procedures for their function allowing input at the outset from other teams. They will then conduct a technical analysis of the iPhone to evaluate potential assembly and maintenance task impact. Finally, the team will release draft procedures and review them periodically to make updates. The teams will rely on mail, calendar services, and other collaboration applications.

- System architecture development: System architecture outlines the overall configuration of the system and is vital to designing and developing a system comprising numerous elements that function as a whole. Each of the teams must define how their hardware and software related activities will affect use of the iPhone.

- Systems performance analyses: Management highlights the system characteristics, system conditions, operational performance, and quantitative system performance.

- Modeling: Simulation teams model each of the subsystems and then the system as a whole along with any deviations from the iPhone's expected or predicted performance. This will be used to reduce cost during testing and verification. Simulation software will be used.

- Integrated test and verification: Testing teams and technicians test the subsystems and then the system as a whole. Safety assessments are performed. Threre will be integrated analyses of the iPhone's test procedures and the data functions to insure interface and safety requirements are satisfied.

- Troubleshooting and anomaly resolution: This final step will involve identification of production and maintenance anomalies; the determination of their causes, and a description of the approaches taken for corrective action. The role of each technical discipline to ensure timely and accurate resolution of the anomalies should be discussed in a technical report from each team. There should be a design review prior to production. Apple should have a customer support representative dedicated to iPhone use in the VAB.

V. IMPLEMENTATION TASKS

The final stage of the systems engineering life cycle is implementation of the new system. Before the system is implemented and fully functional in the NASA workflow, technology required for the new system should be verified, it should be checked whether the new system supports all the processes it will be used in and a prototype of the new system needs to be developed and tested. The results of the tests and evaluations will enable the design engineers to rectify flaws in the system and build a better version of the system for final implementation.

A. TECHNOLOGY VERIFICATION

The pending release for Apple's newest technology, the iPhone, is similar to its Apple predecessors such as the iPod. The iPhone runs on a version of OS X optimized for the iPhone's hardware but still a familiar version to OS X users. The iPhone has a 3.5 inch touch-sensitive display with a resolution of 320 x 480

pixels at 160 pixels per inch, and is more scratch-resistant than the iPod screen. The iPhone is available with either 4 GB or 8 GB. The iPhone has a 2 Megapixel camera, which is essential for technicians to take pictures for procedures or as a means of visual communication. Pictures would enhance the communication between technicians and engineers/supervisors to illustrate where problems exist. The iPhone is a quad-band GSM phone. It works in the U.S and other parts of the world as well while under contract with AT&T. For wireless connectivity, it has a built-in 802.11b/g Wi-Fi. The iPhone also includes Bluetooth 2.0+EDR capabilities. The email client provided in iPhone can be used to access email through iPhone, which supports rich HTML and online images – it resembles OS X's mail application.

Apple also provides free Blackberry-style push IMAP email to all iPhone customers. The iPhone users automatically receive notification when a new email arrives. The iPhone has a number of standard PDA functionalities – storing and displaying contacts, phone numbers, appointments, notes, etc. The iPhone's ability to take notes is an added advantage for technicians as they can notate important information that may be integral to the procedures. The iPod-syncing interface, a 30-pin dock-connector port, allows for data from the computer to be synced into the iPhone. For web browsing, iPhone supports a fully featured version of Safari. For typing emails and entering data, iPhone has an on-screen touch sensitive keyboard. The iPhone does not give a tactile feedback but it features automatic text detection and text prediction; selected keys also enlarge on selection as a form of feedback to the user. Third party applications can be run on the iPhone; however they need to be approved by Apple before they can be (Frakes & Seff, 2007).

B. Process Proofing

The iPhone is an appropriate medium to view electronic procedures since it supports viewing documents, pictures, and videos. An enhanced version of the procedure could incorporate a pictorial description or video to enhance the explanation of the procedural step. Improving the understanding of procedures could increase performance of technicians. The procedures used to build Ares and Orion vehicles will be updated simultaneously as they are built. Any errors in the procedures detected by the technicians would be reported and updated in the PRACA database. Implementation of iPhone would allow technicians to contact their supervisors or engineers to clarify questions about the procedures without leaving their workplace. Any pictures taken during the assembly could be incorporated in the procedure to help later technicians with the task.

In addition to iPhone being used to view electronic procedures, it could also benefit PRACA which is proposed to be used during the building of Ares. The error prediction and recovery systems are shown in Figure 4 and Figure 5 Technicians can use iPhone to view procedures while assembling and manufacturing parts, verify whether the procedures they are following are the latest versions, and report any errors in the procedure. All this can be done from their workplace electronically. If a technician detects an error while assembling a part, he can raise a ticket in the PRACA database by filing an Interim Problem Report, Problem Report or Discrepancy Report and report the error. The PRACA system would alert the supervisor so that he could trace through the procedure to identify where the error has occurred and rectify it. If the procedure is wrong, he would file an Interim Problem Report, Problem Report or Discrepancy Report and update the ticket to alert the design engineer to correct and update the procedure. Once the procedure has been updated, the ticket would be closed. This process would be a detection and prevention of cascading errors. The entire process is executed online, at their respective workplaces.

C. Development test and evaluation

Before the implementation of the iPhone, test and evaluation of the device needs to be performed. The iPhone as well as its case/holder (which can be either strapped to the hand or velcroed to the technician's suit), and electronic procedures are the major items that need to be tested. Visual and audio electronic formats of procedures can be supported by iPhone. Visual formats include written documents or videos. Audio formats include sound bites or video clips. A usability test should be conducted to verify that technicians are able to use the electronic procedure and report errors without compromising with performance on a test PRACA database. Scenarios in which technicians need to access electronic procedures, detect and report errors will also need to be tested. Any short-comings detected with the usability test need to be corrected before iPhone is implemented. Figure 7 and Figure 8 illustrate how the iPhone could be used by technicians.

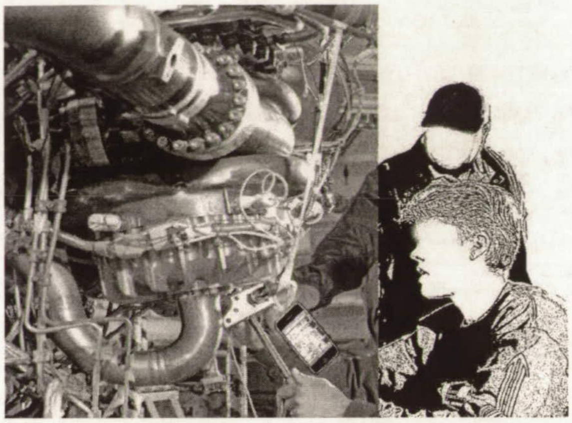


Figure 7: NASA technician performing an assembly task

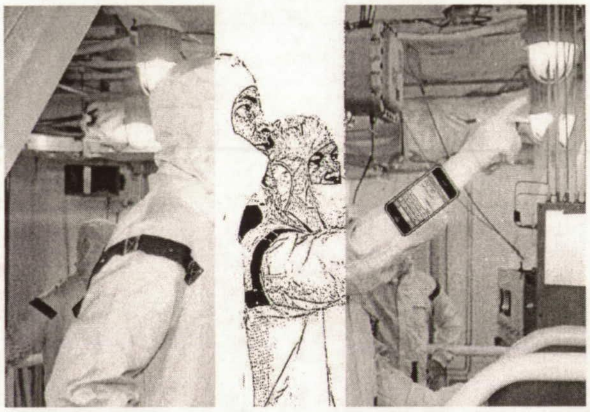


Figure 8: NASA technician uses iPhone to resolve an error

Figure 9 demonstrates a how iPhone can be used to report an error while attached (via Velcro) to a work suit.

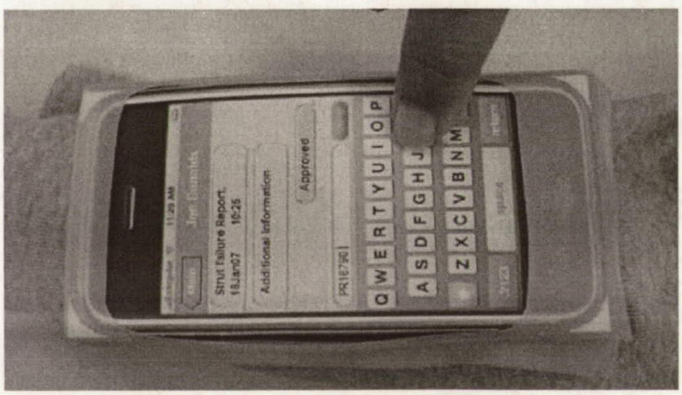


Figure 9: Prototype of an iPhone being used to report an error in the procedure.

Another possible method of wearing iPhone is with elastic straps as shown in Figure 10. This would allow technicians to wear the iPhone regardless if their suits had Velcro or not. The iPhone is in a convenient position to do overhead jobs and look at the procedures at the same time.

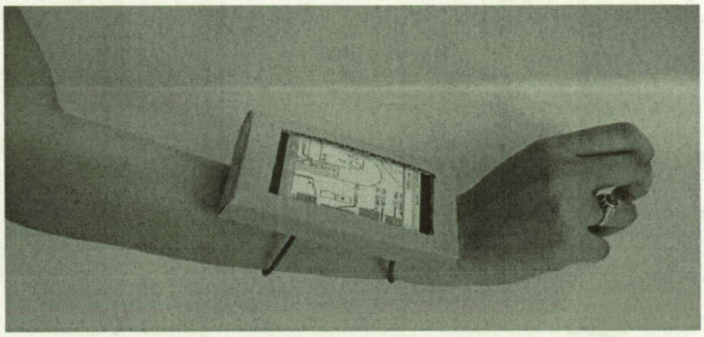
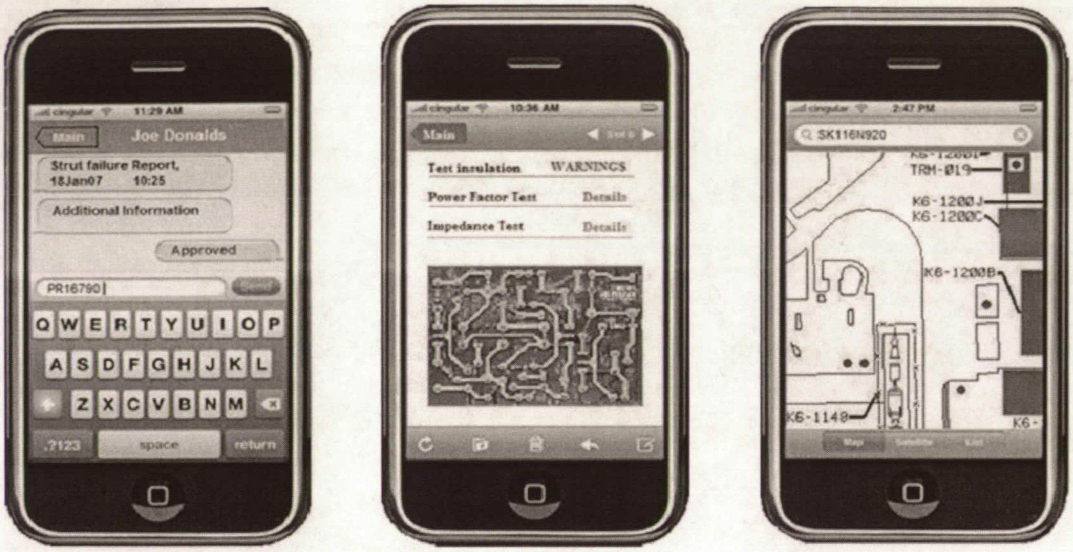


Figure 10: Prototype of an iPhone strapped to the forearm

Figure 11 depicts prototypes screens for different functions that can be performed using the iPhone. Figure 11(a) shows the screen where the user has updated the PRACA database by closing a ticket. Figure 11(b) is a screen-shot of an iPhone displaying a procedure. Figure 11(c) is a screen-shot of the location for the different parts of the assembly that the technician is working on.



(a) (b) (c)

Figure 11: Prototype Screen-shots of iPhone showing NASA functions

D. Generation and Reuse of Software

The PRACA database that would be used to store and update procedures as well as act as an error management system has already been in development by NASA. This database and electronic procedures needed for iPhone implementation can be reused by NASA for other devices and will not be an additional cost to NASA. The introduction of iPhone to ground operations would help NASA more effectively use its resources to reduce time and expenses.

VI. Additional Systems Engineering Activities

Other systems engineering activities could be performed by NASA to ensure that the new proposed system is implement properly. There are two long lead items required for the implementation of the proposed new system, development of the procedure database and infrastructure. Apple iPhone is a commercial off-the-shelf product which will be released in June 2007.

The risk/value proposition of implementing iPhone is extremely low. iPhone would contribute a great deal to the ground operations without increasing any risk. It is acknowledged that there are always risks involved with using technology. However, these risks are low compared to the risk of missing a launch window.

The requirements for the device need to go through a validation process. This will ensure that the device and system have met all the requirements of the technicians. It is recommended that technicians of varying levels and specialties be interviewed to determine if this list encompasses all their needs.

Value Engineering is an organized approach to providing the necessary functions at lowest cost. "Value" is defined as the ratio of Function to Cost. Therefore, value can be increased by either improving the function or reducing the cost. The focus of this system is on reducing risk to have a safe, reliable, cost-effective, and timely launch. The primary goal of Value Engineering is not to reduce the quality as a consequence of pursuing Value improvements (Value Engineering, 2007).Value engineering was not performed for the implementation of the new proposed system since it was beyond the scope of this document. For further evaluation of the proposed system, it could be performed. Generally, during value engineering a more expensive product having a longer expected life or having a lower maintenance cost is recommended.

Other engineering methods and control could be performed by NASA before implementing the proposed system.

VII. CONCLUSIONS

There were two main questions to be answered in this paper: 1) Could ground processing activities at the VAB benefit from the use of a mobile hand held device by their technicians? and 2)Does there an exist an off-the-shelf device that would be able to perform the task efficiently without excessive cost or interruption to the current system?

A review of the literature and historical background of NASA established a need for an easy-to-implement technological improvement to displaying procedures. Previous unsuccessful attempts led to exploring the practicality of using a mobile handheld device. The major products, inputs, resources, constraints, planning and effort required for consideration of this type of solution have been outlined. After analyzing the physical, environmental, life-cycle, functional, and socio-technical requirements, a Functional Analysis was performed to describe the top-level, second-level, and third-level functions of the system requirements. In addition, the risk/value proposition of conversion to a new technology was considered and gave a blueprint for transitioning along with the tasks necessary to implement the device into the VAB's current infrastructure. A WBS described the elemental work items of the implementation.

Once the viability of this system was confirmed, a device needed to be selected. A Pugh Matrix and House of Quality comparison and evaluation of the Apple iPhone, Motorola Q, Blackberry, PC Notebook, and PDA revealed that the iPhone is the most suitable device for this task. Subsequent prototyping and informal laboratory testing confirmed these results. Hundreds of thousands of ground processing person-hours precede every shuttle launch (Semmel et al, 2006) and new time saving approaches to these critical activities could drastically improve efficiency and reduce risks. In conclusion, the advent of the Apple iPhone was the technological gateway to streamlining production for the NASA's Constellation Program work for the next generation of human spacecraft.

VIII. Appendices

A. References

Apple. (2007) iPhone. Retrieved February 26, 2007, from Apple website: http://www.apple.com/iphone/

Baron, J. & Smith, B. (2006). Low-Volume Vehicle Production. *Manufacturing, Engineering, and Technology Group Center for Automotive Research*, Ann Arbor, MI, January 2006.

CityRating. (2002) Orlando Weather History. Retrieved April 6, 2007, from Cityrating.com weather rating website: http://www.cityrating.com/cityweather.asp?city=Orlando

DealTime Ltd. (2007) Sony VAIO® VGN-UX280P PC Notebook: Product Features. Retrieved April 1, 2007, from Dealtime website: http://www.dealtime.com/xPF-Sony-SOLOPROU1400-1-2G-4-5-40G-1G-XP-PRO-BT-2-Built-in-Cameras-Built-in-Microphone-b

Dieter, G.E. (2000). *Engineering Design.* Boston, MA: McGraw Hill.

Fabrycky, W.J., & Mize, J.H. (2006). *Systems Engineering and Analysis.* Upper Saddle River, NJ: Prentice Hall.

Fisher, A. (2005). *How to Battle the Coming Brain Drain*. Fortune, NY: Time Warner Inc.

Frakes, D., & Seff, J. (2007, March). Hello, iPhone: What you need to know about Apple's groundbreaking new gadget. *Macworld*, 24(3), 54-61.

Graves, C., & Lupisella, M., (2004). Applying a Wearable Voice-Activated Computer to Instructional Applications in Clean Room Environments. *Proceedings of IASTED International Conference*, Saint Thomas, Virgin Islands (U.S.), November 22-24.

Humblefrog (2007). Sizeasy. Retrieved April 13, 2007, from International information programs website: http://www.sizeasy.com

International Information Programs (2005). *NASA To Retire Space Shuttle by 2010, Build New Vehicle.* Retrieved April 10, 2007, from (name of the website)website:http://usinfo.state.gov/gi/Archive/2005/May/18-875650.html

KSC (2007). Retrieved March 29, 2007, from Vehicle assembly building website: http://science.ksc.nasa.gov/facilities/vab.html

Linde, C., & Wales, R. (2001). Work process issues in NASA's problem reporting and corrective action (PRACA) database. *NASA Ames Research Center, Human Factors Division, Tech. Rep., 2001.* Retrieved March 29, 2007, from National Aeronautics and Space Administration website: http://human-factors.arc.nasa.gov/april01-workshop/2pg-linde3.doc

Longnecker, D., & Molins, R. (Eds.). (2006). *A Risk Reduction strategy for human exploration of space: a review of NASA's bioastronautics roadmap.* Washington DC: The National Academies Press.

MEI Technologies (2007). Retrieved on April 3, 2007, from (name of the website) website: http://munizengineering.com/Services/sei_disciplines.asp.

Motorola, Inc. (2006). Moto Q. Retrieved April 1, 2007, from Motorola Q specifications website: http://direct.motorola.com/ENS/q-specifications.asp?Country=USA&language=ENS&productid=30419

NASA. (2007a). Retrieved March 15, 2007, from National Aeronautics and Space Administration website: http://www.nasa.gov

NASA. (2007b). FY 2008 Budget Presentation. February 5, 2007.

NASA. (2007c). NASA History Division. Retrieved April 7, 2007, from National Aeronautics and Space Administration website: http://history.nasa.gov/

Palm, Inc. (2007). Trēo 750™ Smartphone. Retrieved April 1, 2007, from Palm Inc. website:http://www.palm.com/us/products/smartphones/treo750/specs.html

PC Magazine. (2007, March 2). BlackBerry 8800. Retrieved April 1, 2007, from PC Magazine website: http://www.pcmag.com/article2/0,1759,2093340,00.asp

Pfarr, B., Rice, M., Fatig, C., & Green, D., (2001). Improving the Capture and Re-Use of Data with Wearable Computers. *Proceedings of IEEE Aerospace Conference*, v.7, Big Sky MT.

Research in Motion. (2007). BlackBerry 8800 Series. Retrieved April 1, 2007, from Blackberry website: http://na.blackberry.com/eng/devices/device-detail.jsp?navId=H0,C201,P403

Semmel, G. S., Davis, S. R., et al. (2006). "Space Shuttle ground processing with monitoring agents." *Intelligent Systems, IEEE* [see *also IEEE Intelligent Systems and Their Applications*] *21*(1), 68-73.

Weather Channel Interactive, Inc. (2007). Monthly Averages for Orlando, FL (32899). Retrieved April 6, 2007, from weather.com website: http://www.weather.com/outlook/travel/businesstraveler/wxclimatology/monthly/graph/32899?from=36hr_bottomnav_business

Value engineering (2007). *Value Engineering*. Retrieved April 9, 2007, from Wikipedia website: http://en.wikipedia.org/wiki/Value_engineering.

Murugappan,M., &. Keeni, G. (2002). Incorporating the Voice of Customer in the Six Sigma Way. *SEPG conference tour in Asia-Pacific*. Retrieved April 25, 2007, from softwaredioxide.com website: http://www.softwaredioxide.com/Channels/Events/SEPG2002/Papers/TCS-Mala.pdf

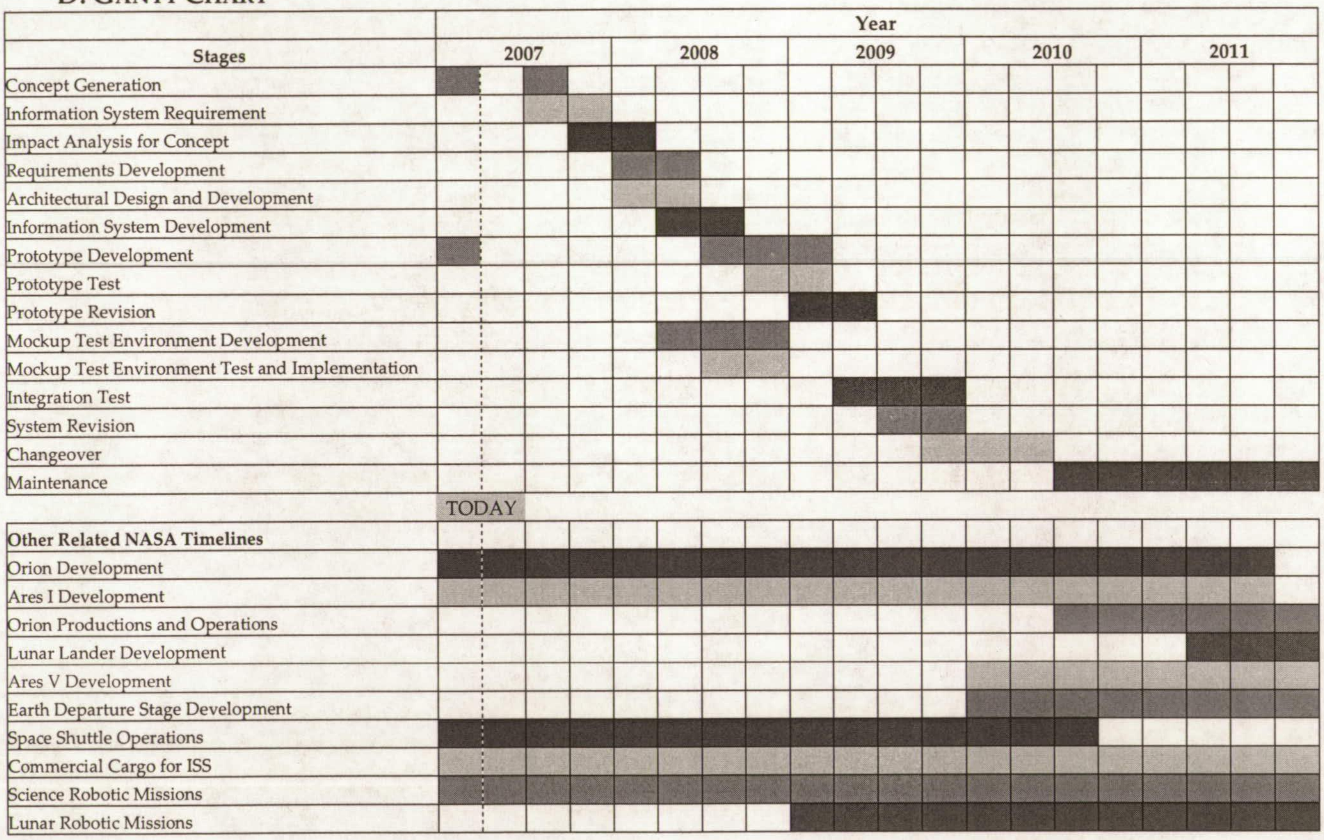
B. ACKNOWLEDGEMENTS

We would like to thank Dr. Barrett Caldwell for his guidance throughout our Human Aspects in Computing class.

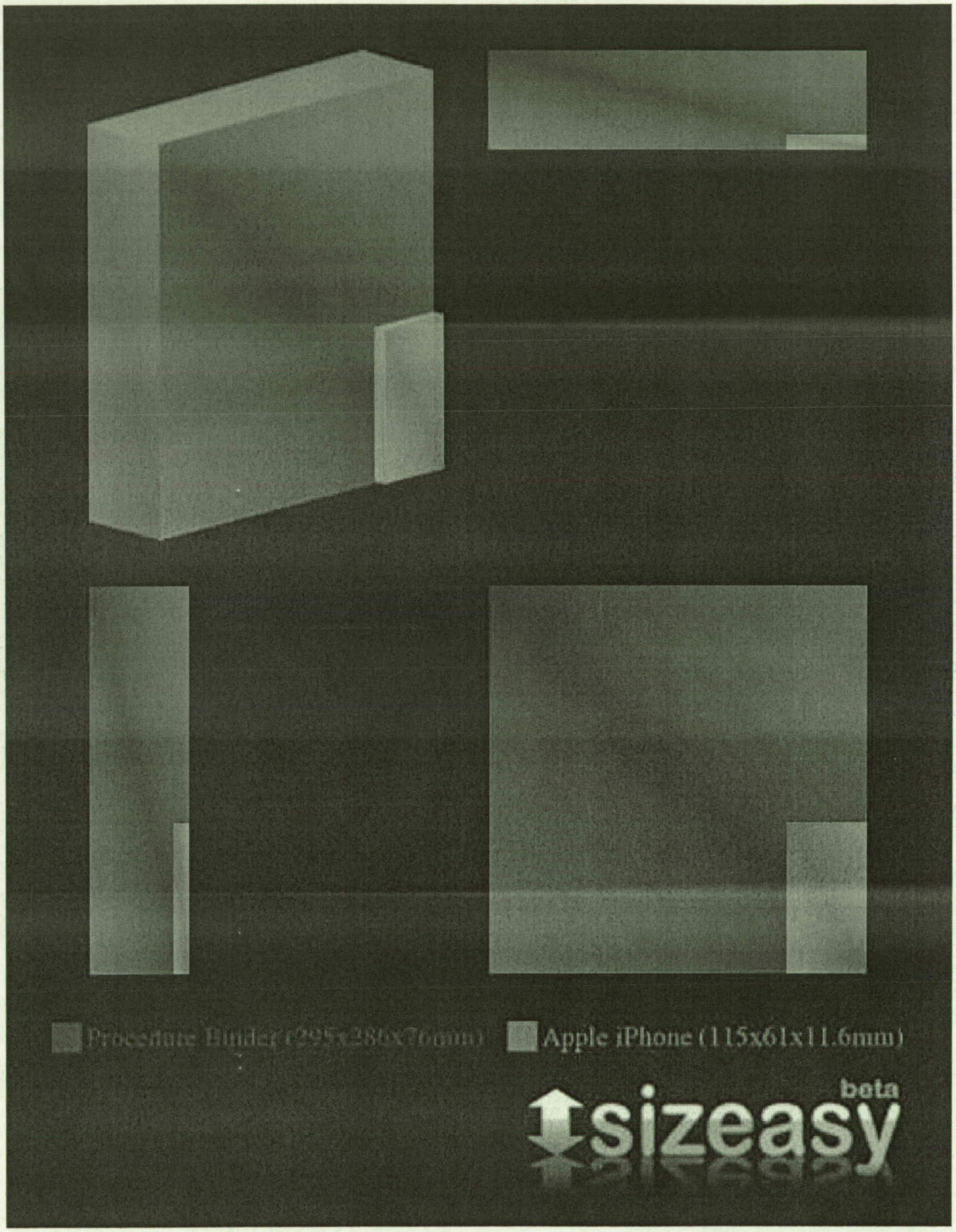
C. WBS

- Concept Generation
- Feasibility Analysis
    - Information System Requirement
    - Impact Analysis for Concept
- Requirements Development
    - Architectural Design and Development
    - Information System Development
- Development
    - Prototype Development
    - Prototype Test
    - Prototype Revision
    - Mockup Test Environment Development
    - Mockup Test Environment Test and Implementation
- Integration Test
- System Revision
- Changeover
- Maintenance

D. Gantt Chart



E. Visual Comparison of iPhone & Paper Procedures (Humblefrog, 2007)



F. iPHONE TECHNICAL SPECS (APPLE, 2007)

G. Risk Assessment Matrix

Risks	Consequence							Relative probability reduction due to iPhone vs. paper (%)
	Missed vehicle launch window	Vehicle rollback	Fatal launch	Underutilized physical resources	Underutilized human resources in VAB	Insufficient testing	Delayed iPhone implementation	
Technical Risks								
Technician unable to access PRACA	L	L			M		H	S
Technician unable to use PRACA satisfactorily				M	M		L	H
Technician unable to access procedure(s)	M	M	L		M	L	H	S
Technician unable to access updated procedure(s) satisfactorily	H	H	M	M	M	L	L	H
Technician unable to raise problem in PRACA	L			M	L		H	M
Technician unable to raise a Procedure Change Request	L	L		M	L		H	M
Technician uses wrong / old procedure	L	M	M	M		L		H
Engineer not able to comprehend problem from report		L	L	M	M	L		M
Technician does not have data to complete procedure step	L	M	L	M		L		H
Problem not reported completely	L		M			M		M
Technician does not have data to fill out work forms				L	L			S
Rollback of procedure is not conveyed to everyone	M	L	L				L	H
Defective component not reported	H		H	L		L		H
Defective design not reported	H		H		L	L		H
Problem resolution not conveyed immediately to related personnel	M		L		L	L		H
Problem not reported immediately to related personnel	M	L	L		M	M	L	H
Technician not able to file report in a timely manner	L			M	M		M	M
System usage statistics not captured (rephrase this)	L	L		M	L		M	H
Slow /Delayed update	L			L		L	M	H
Cost Risks								
Guarantee and Warranty costs are over budget							M	-
Product cost increment soon after implementation				L		L	M	-
Software transition exceeds complexity and budget	L					L	M	-
Schedule Risks								
Contract negotiation with product vendor (Apple Inc) prolongs							H	-
Program Risks								
Private contractor for repair is not acceptable				L	L		H	-
Smaller number of iPhones acquired	L				L	L		-
Delayed funding for project implementation	L			L			H	-

Consequence Scale: L – Low M – Medium H – High

Probability Scale: S – Small M – Medium H – High

H. Pugh Matrix

Features	iPhone	Motorola Q	Blackberry	PC Notebook	PDA
Physical					
Model	-	-	8800	Sony VAIO VGN-UX280P	Trēo 750
Weight (oz)	4.8	4.1	4.73	19.2	5.4
Size (in) [Volume (in³)]	4.5 x 2.4 x 0.46 [4.97]	4.57 x 2.52 x 0.45 [5.18]	4.49 x 2.60 x 0.55 [6.42]	5.91 x 1.5 x 3.74 [33.16]	4.44 x 2.3 x 0.8 [8.17]
Memory (MB)	8,000	128	64	1,024	60
Battery Life (hr)	5	4	5	4.5	4
Communication					
Phone	yes	yes	yes	no	yes
Wireless	yes	yes	yes	yes	yes
Internet	yes	yes	yes	yes	yes
Email	yes	yes	yes	yes	yes
Display					
Backlit	yes	no	yes	no	yes
Light Sensing	yes	no	yes	no	no
Screen Size (px)	320 x 480	320 x 240	320 x 240	1024 x 600	240 x 240
Additional					
Provider	AT&T	Verizon	AT&T	-	AT&T
System	OS X	PC	Blackberry OS	PC	PC
Camera	yes	yes	no	no	yes
Cost	$599.00	$99.99	$299.99	$1,603.93	$399.00

Features	Desired Value
Physical	
Weight (oz)	small
Size (in) [Volume (in³)]	small
Memory (MB)	large
Battery Life (hr)	large
Communication	
Phone	yes
Display	
Backlit	yes
Light Sensing	yes
Screen Size (pixels)	large
Additional	
Camera	yes

Ratings: + = better, s = same, - = worse

Iteration #1

FEATURES	PC NOTEBOOK	MOTOROLA Q	BLACKBERRY	iPHONE	PDA
Weight		+	+	+	+
Size [Volume]		+	+	+	+
Memory		-	-	+	-
Battery Life		-	+	+	-
Phone	DATUM	+	+	+	+
Backlit		S	+	+	+
Light Sensing		S	+	+	S
Screen Size		-	-	-	-
Camera		+	S	+	+
Σ +		4	6	8	5
Σ S		2	1	0	1
Σ -		3	2	1	3
TOTAL		1	4	7	2

Iteration #2

FEATURES	PC NOTEBOOK	MOTOROLA Q	BLACKBERRY	iPHONE	PDA
Weight	-		+	-	-
Size [Volume]	-		-	+	-
Memory	+		-	+	-
Battery Life	+		+	+	-
Phone	-	DATUM	S	S	S
Backlit	-		+	+	+
Light Sensing	-		+	+	-
Screen Size	+		S	+	-
Camera	-		-	+	+
Σ +	3		4	7	2
Σ S	0		2	1	1
Σ -	6		3	1	6
TOTAL	-3		1	6	-4

Iteration #3

FEATURES	PC NOTEBOOK	MOTOROLA Q	BLACKBERRY	iPHONE	PDA
Weight	-	+	DATUM	-	-
Size [Volume]	-	+		+	-
Memory	+	-		+	-
Battery Life	-	-		S	-
Phone	-	S		S	S
Backlit	-	-		S	S
Light Sensing	-	-		S	-
Screen Size	+	S		+	-
Camera	-	S		+	S
Σ+	2	2		4	0
ΣS	0	3		4	3
Σ-	7	4		1	6
TOTAL	-5	-2		3	-6

iPhone is the preferred technology.

I. Functional Analysis and Allocation Documentation

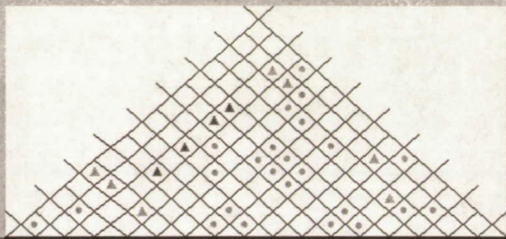
Activity Number	Activity Description	Required Inputs	Expected Outputs	Resource Requirements
1.0	Identification of Need	A qualitative and quantitative needs statement.	Revision of current administrative initiatives; update of current mission. NASA assessment of Orion space mission timeline.	Bush administration's promise to return to the moon in the next decade.
2.0	Presidential and NASA Vision Announcement	Identification of need; constituent feedback; mission challenges; acceleration of space programs in other countries.	NASA centers release new agendas supporting new vision. Release/Publish official requests for proposals.	Supplier qualification. Report and presentation to management.
3.0	CEV Contract Awarded	Submission of bids through government contracting officer. Vendor selection process.	Begin planning and preparation for design phases. Vendor awarded based on cost and matching criteria in Presidential and NASA Vision Announcement.	Bid reviews and Supplier selection. Conceptual design and Functional requirements.
4.0	Technological Advancement	Mobile computing Based on changing societal needs, demands, market surveys, and competitive product research.	Innovation and Inventions relevant to space flight.	Benchmarking. Research.
5.0	KSC Ground Operations Initiative	Based on NASA mission and available technology.	KSC departments push towards meeting new goals	Out-year plans from all divisions.
5.1	Ground Operations funding approved	Request sent to NASA HQ based on new initiative	VAB building prioritizes usability, safety, maintainability, and reliability.	Preliminary cost estimate.
5.2	Conduct Benefit/Cost Analysis	Orion and Ares preliminary designs.	Elimination and selection of feasible designs.	Boundaries of the design. Final cost estimate

Activity Number	Activity Description	Required Inputs	Expected Outputs	Resource Requirements
5.3	Analysis of conceptual system design alternatives	Requires funding and preliminary designs. Definition of design and success criteria. Evaluation of iPhone, Motorola Q, Blackberry, PC Notebook, and PDA.	Shift towards specific design and/or production methods.	Risk analyses; conceptual system design evaluation and display; creative and meaningful alternatives.
5.4	Management Alignment	Organization of personnel and resources once funding has been approved. Management strategy and planning.	Operations and staffing plan. Technician and other support personnel alignment.	Retention, Development, Promotion to overcome internal assumptions and align management and staff. Workshops.
5.5	Determine Human factors Requirements	Requires management strategy.	Verification of existing and new methods.	Prototypes and Mock-ups; high fidelity testing environment.
5.6	Establish production requirements	Based on management alignment and resource scheduling.	Scheduling. Final cost estimate.	Gantt Chart; brainstorming; analogy; and checklists.
5.6.1	VAB facility compliance	Notification to VAB support personnel of production schedule	Building, System, and Equipment layouts.	Facility Compliance to Inspection Environmental and safety programs based on NASA standards.
5.6.2	Train Technicians	Technicians trained in safety compliant facility	Receive feedback from technicians on operation support needs.	Simulation tools and training workshops through cooperation with Apple Computer training staff and VAB building management.
5.6.3	Acquire Test and support equipment	Requires facility and supporting equipment specifications	May require system maintenance and compatibility updates of current system	New software. Vulnerability and serviceability issues addressed.
5.6.4	Upload Procedures and supplemental data	Can be done once the iPhone has met the production schedule.	Documentation of lessons learned.	Technical Support; existing procedures. Reduction of re-work.

Activity Number	Activity Description	Required Inputs	Expected Outputs	Resource Requirements
5.6.5	Documentation of lessons learned	Ongoing during implementation and use	Knowledge sharing.	Lessons-Learned Database serves as a clearinghouse in order to apply the lessons learned to future project phases.
5.6.6	System operation and maintenance	Ongoing during implementation and use.	Documentation of lessons learned.	System Operation and Maintenance Program works to ensure that systems are located and installed correctly and kept in top working condition.
5.7	iPhone Acquisition	Release and delivery of iPhone.	Testing and verification. Operating and implementation procedures. Logistics issues.	Purchase order and maintenance contract with Apple.
5.8	Test the system in user environment	Requires acquisition of iPhone and development of system test modules.	Troubleshooting; testing to ensure that user tasks are correctly mapped within iPhone context and test environment.	iPhone; data Collection and statistical analysis. System integration testing,

J. House of Quality

•	Strong Negative Relationship
▲	Negative Relationship
•	Strong Positive Relationship
▲	Positive Relationship
⇓	Negatively correlated
⇑	Positively correlated



Customer Importance/ Planning Matrix
1 - Low
5 - High
Requirements Relationship
1 - Low
3 - Moderate
9 - Strong

		Direction of Improvement		⇓	⇓	⇑	⇑	⇑	s	s	s	s	⇑	⇑	s	s	⇑	⇑	⇑	⇑	Planning Matrix					
		Technical Requirements		Performance Measure						Techinical Details																
Customer Requirements			Customer Importance	Weight	Size	Battery Life	Screen Size	Storage Capacity	Input Device	GSM wireless tech	WiFi	Bluetooth	Digital camera	Readability	Web Browser capable	HTML Email client	Resists Scratches and Dent	Programmable	Guaranteed warrantee	Screen magnification	iPhone	Paper (Current)	MotoQ	PC Notebook	Blackberry	PDA
Facilitate Climbing	Physical	Should be able to fit on one hand / other body part with or without slight attachements	5		9																4	1	4	1	4	3
		Should be light enough to be carried around for 3 hours without discomfort	4	9	3				1												4	1	4	1	4	4
		Should be easily portable with minimal cable attachements	5			3			9		3	3									3	1	3	1	3	3
		Should be able to remove / attach easily	2	9	9				3												3	3	3	1	3	3
		Should not require extensive training before usage	2						3												4	4	4	4	4	4
		Input device should not be overtly sensitive	2						9												3	5	3	4	3	3
	Functional Performance	Should not provide any radio signal interference with critical frequencies	4							3	3										4	5	3	5	3	3
		Should provide backlight for dimly lit work areas	4				9							9							5	1	1	1	5	3
		Can access electronic media	5				1	1			3				9	3					5	5	5	5	5	5
		Can access internet, email	5				1				9				9	9					5	5	5	5	5	5
		Can take outgoing and incoming calls	4							9		1									5	1	5	1	5	5
		Battery life is atleast 4 hours	4			9															5	5	3	4	5	3
		Can take pictures	4				1	3					9							1	4	1	4	1	1	4
		Features can be enhanced routinely; easily programmable	3								3							9			3	1	4	5	3	4
		User should be able to make notes	4				3	3	3							3		9		1	4	5	4	4	4	4
	Life Cycle	Durable	4														9				3	3	3	3	3	3
		Low cost	1					3	3				1				3	3	9		2	5	5	1	4	3
		Low Maintenance	2			3											9				4	1	4	4	4	4
		High Reliability (Low mean time to failure)	4			9											3		3		3	5	3	3	3	3
	Social	Should not cause physical damage to user	5	3	3												1				5	5	5	5	5	5
		Absolute Importance		69	90	93	62	32	94	48	96	19	37	36	90	72	74	66	21	8	Customer Satisfaction					
		Relative Importance		6.9	8.9	9.2	6.2	3.2	9.3	4.8	9.5	1.9	3.7	3.6	8.9	7.1	7.3	6.6	2.1	0.8	297	227	275	219	283	276
		Design Targets		< 5 oz	< 10 inch^3	> 4 hours	> 340 x 240 px	> 128 MB	Comply	Comply	802.11b/g	Atleast 2.0	> 1 Mpx	Comply	Comply	Comply	Comply	Comply	Comply	> 4X						